Key to Successful Retrofitting in Bridge Maintenance

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ABSTRACT

Repair and retrofitting works of existing bridge structures require wide range of design talents and construction skills. Repair works are often conducted in poor site working condition and it sometimes becomes hard to achieve planned quality and performance or in the worst case, makes structure's life shorter due to wrong treatments. This paper reports several unsuccessful or unfavorable repair cases of existing steel bridges. Common error in unsuccessful case is absence of 'checking and improving processes' in design flow. Those processes should be included to pay attention on site working condition, cost performance of the repair in long time span. Various topics are discussed here, such as adjustment of member size, exchange of support bearing and core drilling for it, securement of working space, redistribution of dead load force in existing structure due to removal of members, transportation of members to a destination, drilling and tightening of anchor bolt for skewed bridge, and so force.

1. INTRODUCTION

Maintenances of existing bridge structure are regarded as matter of high importance and raised the priority in construction budget. Design and construction technique concerning repair and retrofitting has been progressing these days. Rational distribution of maintenance budget including validation to law is widely discussed in Japan. Retrofit of damaged structure requires high level of engineering, which is not only knowledge about cause and mechanism of damage but deep understanding about actual structural details and behavior. After the collapse of Minnesota I-35W truss bridge (**Fig.1**), intensive investigations with respect to the health condition of truss type bridges were enforced in Japan and some quite serious damage were found. One example shown in **Fig.2** is a breaking of diagonal truss member due to combination of corrosion and fatigue in the steel member inserted into concrete slab in the Kiso River Bridge found in June, 2008. Ongoing intensive inspection revealed other critically damaged bridges. Review points in construction are referred in following topics in this paper, handling of members, securement of working space, adjustment of location, dead load carried by structural members, fitness for purpose

Fig.1 Collapse of Minesota I-35W

Fig.2 Breaking of a member in Kiso Riber Bridge i

2. INTERACTION BETWEEN DESIGN AND CONSTRUCTION IN RETROFITTING

Poor construction condition makes it difficult to achieve original design requirement concerning structural performance and quality in retrofit work. Or doing retrofit in such a bad condition makes structures worse or shortens its life. It is inevitable to relate all the process in retrofitting work such as design, planning, and construction in order to resolve those inherent problems. Design flow of repair and retrofit is shown in FIg.3.

When damage or deterioration of a structure is detected, Retrofit method is determined in basic design or planning phase which require high level of intelligent creative activities based on high level of technical skill. This step is treated as part of decision making “Need to repair?” in Fig.3, which include study about whether the repair work is necessary or not and how much money is required for it. People pay small attentions or neglect this basic design, and quickly move to detail design. But actually, this basic design influences a lot on following detail design and products quality. More time and cost should be spent on this step than newly built structures.

Detail design should include construction planning or both are tightly related together. There are cases where detail design is not optimized under the actual site construction condition, and modifications of design in the construction phase will cause unexpected expense and decline of the quality. It should be noted that relation between detail designer and constructor should be looked again.

It is necessary to pay attention on the balance between performance and cost under the construction restrictions. If the cost to complete the retrofitting work under given restrictions is too much against the expected improvement of structure, the retrofitting method is studied again.

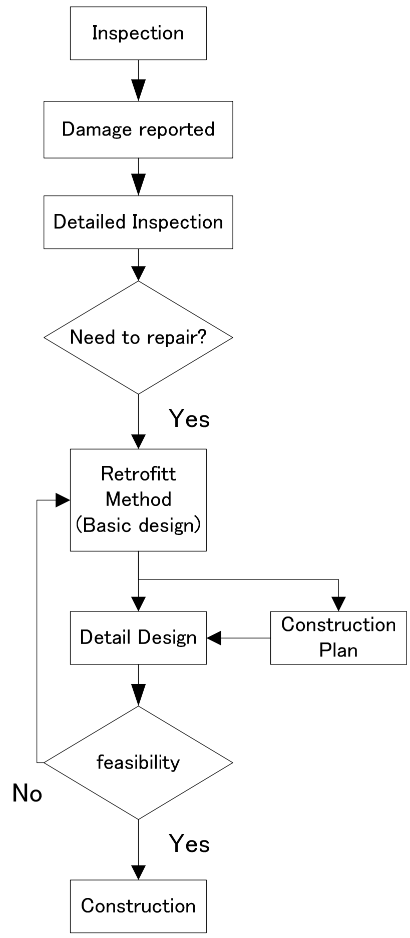


Fig.3 Work Flow for Retrofitting

3. UNSUCCESSFUL OR UNFAVORABLE REPAIR CASES

3.1 Margin for size error

Fatigue cracks were found at the boxing weld of lower web gap plate for the connection between longitudinal girder and cross girder. This fatigue crack is found at the conjunction of longitudinal member and transverse members. Cause of this crack is the existence of end moment at the connection produced by the deflection of longitudinal girder. Attachments are inserted to the gap between lower flange of longitudinal girder and lower flange of cross girder as shown in Fig 4. The attachment is bracket type rib supporting end moment of longitudinal girder.

Problem with this attachment was that the gap between both flanges were not constant and some of them were too small for the attachment and there are no margin for it. Existing structures always have fluctuation of size that is not mentioned in design drawing. They are caused by time dependent inelastic deflection, dead load deflection, fabrication error and so forth. It is preferable to check actual size of space to set beforehand and design new member to fit into the space or allow such margin.

They ground lower flange of existing members to increase the space for attachments first but the construction schedule was delayed due to the grinding works. Then they changed height of attachments smaller and use filler plate to fill a gap.

Flange of the attachment is bent by press machine and full penetration is required for welding. There exists possibility of size error. Adjustment function should have been implemented in the attachment.

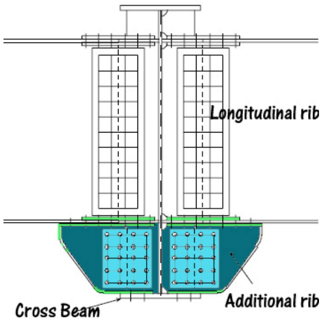


Fig.4(a) Attachment Sideview

Fig.4(b)Bracket Stiffener

Fig.4(c) Bracket Stiffener

3.2 Securement of working space (1)

The two box girder bridge with one bearing in each girder was to replace support bearing. For replacement of support bearing, it was necessary to make holes in concrete substructures for setting anchor bolt by using core drilling machine shown in Fig.5b. There was 500 mm clearance below the lower flange and drilling was hard in that clearance because of anchor bolt length and height of the drilling machine.

In original plan, core drilling machine was set inside of box girder and drilling was executed through the holes opened in the lower flange of box girders. But it turned out that there had been no consideration about the reinforcement bar in base concrete and search of reinforcement bar in deep location is not easy job. With this drilling method, it is not possible to change anchor bolt location to avoid interference with the reinforcement bar.

Original plan was changed in construction step. All the works in box girder are changed to complete under the lower flange of the box girder. Core drill machine is modified from 650 mm height to 450 mm height. Anchor bolts are cut into two peaces and screw type cupla is used to connect two of them. Gather information widely from equipment maker or professional in that field may help to get the right answer.

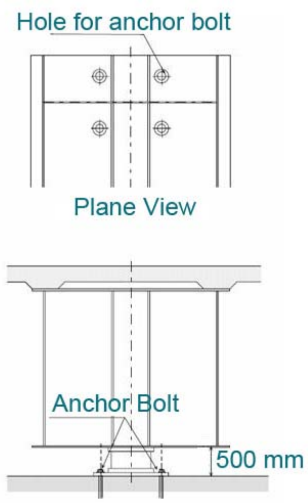


Fig.5(a) Original plan

Fig. 5(b) Core drilling machine

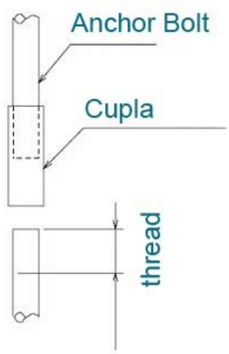


Fig.5(c) Bracket Stiffener

3.3 Securement of working space (2)

Head of rivet bolt were rusted and partly damaged severely in a bridge and it needed replacement. Replacement of rivet bolts to high tension bolt was planned and ordered to constructor. But it turned out that damaged rivet bolts used in gusset plates located too close to the railing of bridge and there were small clearances between them (Fig.6.) Since the replacements of rivet bolt in such a narrow space are not easy without removing other obstacle structure, such as railing, part of deck, the replacement of rivet was canceled until the other large scale rehabilitation work.

This problem results from the fact that replacement of rivet had never been considered in this bridge from the initial construction. Preparatory study including on-site detail check is inevitable for repair and retrofit. It sometimes happens that a designer makes plan with limited information, such as pictures taken by different purposes, original old drawing, and so force.

Fig.6(a) Rivet bolt to be replaced

Fig.6(b) Rivet bolt gusset close to the deck

3.4 Dead load stress

Bracket and its supporting beam were to be installed in I girder bridge in order to support a new sign board. To install the supporting cross beam, it was necessary to remove cross bracing between girders near the lower flange (Fig.7(a)). Generally, the cross bracing had been set before the casting of slab concrete and the camber changed after the concrete casting introduced residual force in brace members especially in curved girder. If the force is large, it would become hard to set the removed member back in the right position due to the misalignment of bolt holes. And in extreme case, dead load camber might change.

In order to avoid anticipated camber change due to the member removal, original cross beam is divided into three peaces and set without removing the cross bracing.

It is necessary to pay attention on dead load stress in primary members, which can be assumed by design calculations. But stresses are influenced by erection sequence and hard to know precisely, especially in secondary members. It is preferable to use bent and conduct retrofitting work under stress free condition, or caution must be paid to the residual force. And removing of existing members should be done after understanding the residual force.

Fig.7(a) Cross bracings of curved girder

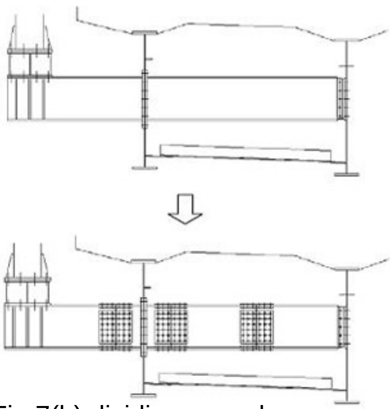


Fig.7(b) dividing cross beam

3,5 Handling of attachment members

Safety protection cables were to be attached to protect bridge girder from fall down or collapse in case the bridge moves large distance under unexpected earth quake. Supporting beams in the box girder were required to support cable anchoring brackets attached beneath the box girder (Fig.8(a)). But it turned out that the beam was too large to insert into the box girder. And owner didn’t want to open new manhole to insert the beam.

After the study about the solution, supporting beams were divided into several peaces and brought into the box from girder end opening as shown in Fig.8(b),(c). In repair and retrofitting works, regardless of how desirable the designs are, there is no use without considering the feasibility of the proposed solution, concerning limitation of space for working, transportation of members, and handling of equipments, such as crane, jack. Attachment members with light weight and small size will often result in better quality and lower cost, especially inside of closed spaces, such as box girder. Lack of consideration with respect to material handling in design phase will result in this kind of unfavorable detail change (Fig.8(d).)

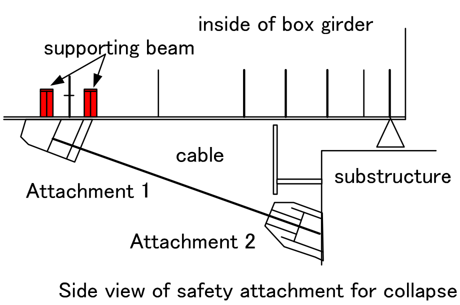


Fig.8(a) Supporting beam for attachment 1 attachment

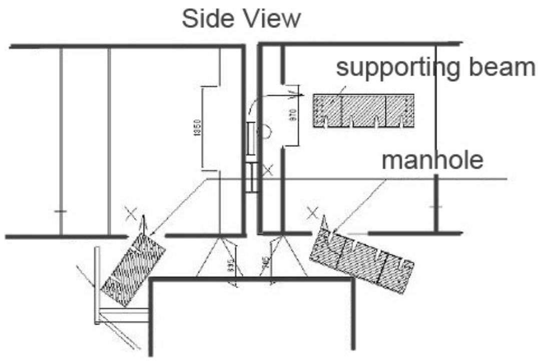


Fig.8(b) Planning view to insert supporting beam

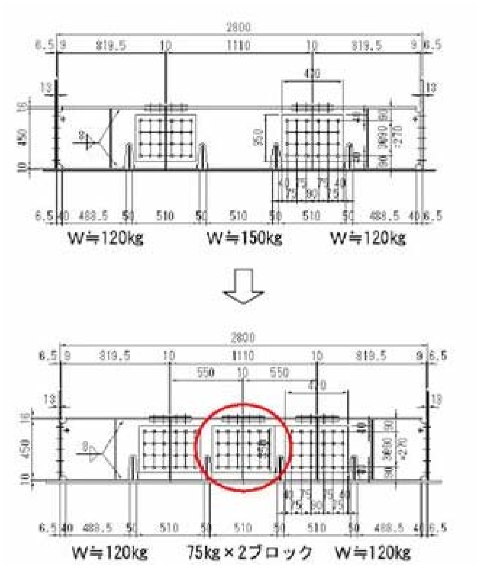


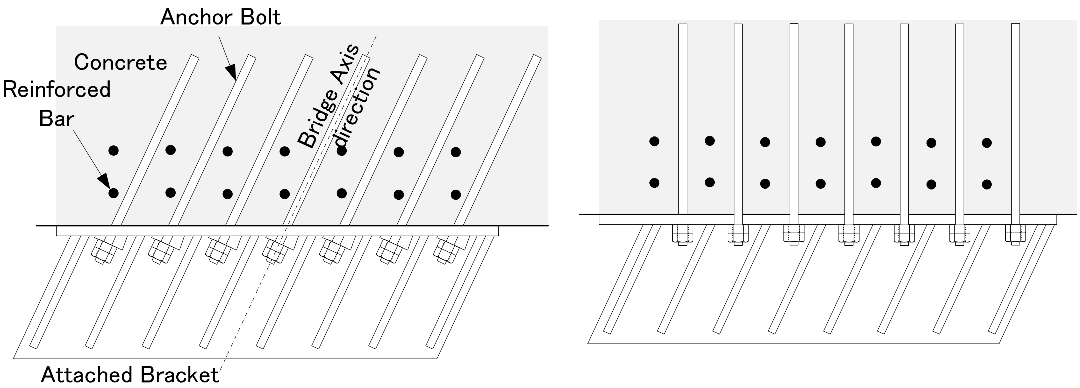
Fig.8(c) Additional splice on supporting beam

Fig.8(d) Final appearance of supporting beam

3.6 design to fit the required performance

Extension brackets were designed to safely support a bride against falling down. Steel brackets to extend the supporting place for the girder to sit on in case of large earthquake were designed. The longitudinal direction of this bridge differs from substructure's direction and direction of the original bracket and anchor bolts were parallel with the bridge longitudinal direction. But this type of inclined bracket has following problems. It is very difficult to execute core drilling without cutting reinforcing bar if they don't know the location of reinforcement bars precisely in abatement. Welding of these inclined ribs is hard to complete. Tightening of anchor nuts on site is also hard without preparing special details for the work.

As a result, the directions of anchor bolts were changed to run parallel to the substructure's direction. It is not easy to complete core drilling for anchor bolts without touching reinforcement bar. Core drilling with angle is far more risky task and should be avoided. Bracket was made to be parallel to bridge axis in this case but Square shape bracket is far easier to make with good quality of welding and preciseness. Choose square detail if it can satisfy required performance. Requirements of retrofit structure should have been confirmed in basic design phase before the detail design. This kind of poor detail can be called design failure if square bracket could be accepted.



(a) Original bracket design (b) Modified bracket design

Fig.9 bracket attached to substructure

4. STANDARD CONSTRUCTION METHODS FOR STEEL BRIDGE RETROFITTING

Retrofitting works require different kind of skill from new bridge construction, different kind of equipment from shop fabrication. Examples of special technique and equipment for repair and retrofitting, such as drilling with existing structure, replacement of rivet bolt, or setting of members in narrow, confined space. Standard retrofitting works are introduced hereafter.

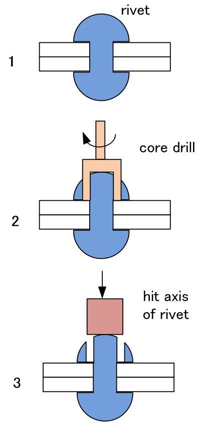
4.1 replacement of rivet

There are cases when rivet bolt holes of old steel structure are used to attach new members. Removal of rivet is not a special job in retrofitting field these days. Removal sequence of rivet is shown in Fig.10(d). In order to replace old corroded rivet to HT bolt, core drilling machine is used to separate head of rivet at first (Fig.10 (a), Fig.10 (d) step2). Then rivet is removed from plate by pushing axis of rivet (Fig.10(d) step3).

(a) Drilled rivet

(b) removal of rivet

(c) removed rivet



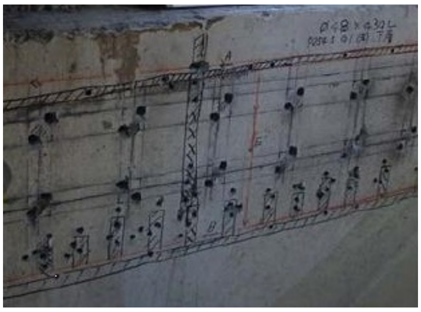
(d) Sequence of rivet removal

Fig.10 Removal of rivet

4.2 Anchor bolt setting

Anchor bolts are widely used to attach such steel members as a bracket and a beam to concrete substructure. They are used as a part of anchoring or displacement restriction system to safely protect superstructures against falling downs during large earthquake. Sequence and equipments used for the work are shown in Fig.11. In order not to cut the reinforcement bar in concrete, electromagnetic radiation radar shown in (a) is used. But there is a limitation of censing depth and minimum interval of bars with this radar and it is not always possible to avoid hitting reinforcement bar only from these information. To avoid cutting of reinforcement bars, pilot hole drilling is executed to assure the location of reinforcement bar (b). Core drilling is generally executed by diamond core drill (c). Metal censer code reel (e), which can stop power supply in case drill bit touches reinforcement bar. Water jet is also used for the same purpose.

(a) electromagnetic radiation radar



(b) pilot hole drilling

(e) metal censer code reel

(c) diamond core drilling

(d) after core drilling

Fig.11 Core drilling for anchor bolt

4.3 Drilling in field

Handy type drilling machines are available these days and drilling in field becomes easier than before. But drilling in narrow confined space is still hard work and such poor working condition becomes burden for aged field construction workers. Improvement of field drilling equipment is on urgent problem. Fig.12 shows example of drilling in field. (a) is handy type drill machine used for core drilling in girder web. (b) shows replacement of longitudinal trough rib orthotropic steel deck.bridge. (c) is drilling of horizontal stiffenner of steel girder to attach a splice member. (d) is drilling from inside of truss chord member.

(a) drilling in girder web

(b) drilling in longitudinal trough rib

(c) drilling in narrow space

(d) drilling in truss node

Fig.12 drilling in the field

5. Conclusion

Repair and retrofitting works are performed under the bad working conditions and it is not always possible to satisfy all the required qualities. It is crucial to grasp site conditions in order to plan retrofitting with well balancing performance and quality. Cost efficiency is also the point ro remember. Maintenance cost planning is inevitable to accommodate unexpected cost increase for aging structures in the near future. Bridge engineers are responsible to preserve the social capital and provide a favorable influence in strengthening the social infrastructure.